10/585150

IAP20 Rec'd PCT/PTO 30 JUN 2006

A METHOD FOR MEASURING THE OPERATING STATE OF SYNCHRONOUS MOTOR BY USING COMPOSITE POWER ANGLE METER

FIELD OF THE INVENTION

The present invention relates to a method for measuring the operating state of synchronous motor by using composite power angle meter, which belongs to the field of electrical engineering in electric power systems.

BACKGROUND OF THE INVENTION

In the industrial practice of electric power systems, it is necessary to constantly monitor the operating state of a synchronous motor, so as to ensure the synchronous motor to operate in an optimum state. At present, an electric power system generally adopts, at operating locales, various types of meters to display the current, voltage, power and other related electric data of the synchronous motor, especially adopts a power angle meter to measure the power angle and other related electric data of the synchronous motor, and displays the electric power angle vector graph of the synchronous motor through a TV screen (as shown in Figures 6 and 15), so as to provide intuitional electric vector graph for operators.

However, there are disadvantages in various electric measuring meters currently in use. For example, the defects of the power angle meter which is capable of displaying the electric data and electric vector graph of a salient-pole synchronous motor are:

1. The power angle meter can only display the electric power angle vector graph of the synchronous motor (as shown in Figure 6), but it cannot directly display the mechanical relationship between the stator and the rotor of the synchronous motor.

2. Although the power angle meter can display the electric power angle vector graph of the synchronous motor and reflect the stator armature potential, magnetic excitation potential, motor-end voltage, power angle and other electric data of the synchronous motor, it cannot display, with optimum segments, the magnitudes of

active power and reactive power of the synchronous motor or the magnitudes of active components and reactive components of other parameters of the synchronous motor.

3. The power angle meter cannot satisfy the requirements of various professionals working in synchronous motor monitoring and operating. With the development of electric technology, a majority of dynamotor sets in the power plants realize the centralized control by programs. Compared with the number of other professionals, the number of electric professionals working in dynamotor monitoring and operating is less and less. However, it is difficult for non-electric professionals to understand the electric power angle vector graph displayed by the power angle meter of the synchronous motor.

4. The power angle meter cannot be applied to synchronous parallel-network monitoring of the synchronous motor.

5. The power angle meter cannot display the end magnetic leakage condition of the synchronous motor.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention aims at providing a method for measuring the operating state of a synchronous motor by using composite power angle meter. The method can intuitionally reflect various operating states of a synchronous motor from both electric and mechanical aspects, is advantageous for operators of various specialties to dialectically understand the operation principle of the synchronous motor from both electric and mechanical aspects, provides an intuitional model for mechanical analysis of the parallel-network operating state of the synchronous motor, and provides operators with images for analyzing and monitoring the end heat-emitting condition of the synchronous motor by depicting the end composite magnetic leakage graph of the synchronous motor.

In order to achieve the above object, one aspect of the present invention provides a method for measuring the operating state of synchronous motor by using composite power angle meter, which comprises steps of:

a) Obtaining various electric signals of the synchronous motor and its system, and obtaining digital signals of related equipments;

b) Converting the electric signals into digital signals by an internal data collection part of the composite power angle meter, and inputting related digital signals to a host computer;

c) Inputting related parameters or commands to the host computer by keyboard and mouse;

d) Program-processing the related data by the computer, calculating the data by a computing program to obtain the coordinates of relevant points and related data, and inputting the results to a displaying program;

e) Using the coordinates of main points and the calculation results to depict various electric and mechanical model graphs of the synchronous motor through the displaying program process by the computer, displaying on a display a dynamic composite power angle graph which varies with the motor's parameters, and realizing an alarm function;

f) Using the coordinates of main points and the calculation results to depict the end composite magnetic leakage graph of the synchronous motor through the displaying program process by the computer, displaying on a display an end composite magnetic leakage graph of the synchronous motor which varies with the motor's parameters, and realizing an alarm function.

The present invention provides a method for measuring the operating state of a synchronous motor by using composite power angle meter, wherein program processes comprise a displaying program process and a computing program process; the displaying program process comprises establishing graph coordinates and imaging; and the computing program process comprises determining parameters, calculating parameters and alarming.

The above aspect of the present invention uses a composite power angle meter to obtain the stator voltage and current signals, magnetic excitation voltage and current signals, magnetic excitation adjustment signal and system voltage signal of the synchronous motor in real time, performs internal controlling programs to calculate the related parameters of the synchronous motor in real time, depicts the electric and mechanical model

graphs illustrating various characteristics of the synchronous motor, depicts the end composite magnetic leakage graph of the synchronous motor, and displays the graphs on a display. Therefore, compared with conventional methods for measuring the operating state of a synchronous motor by using power angle meter, the present invention has the following advantages:

1. The present invention may intuitionally reflect the operating state of a synchronous motor from both electric and mechanical aspects. The present invention may not only display the electric power angle vector graph of the synchronous motor, but also display the composite power angle graph, motor mechanical model graph, motor mechanical model schematic graph and motor synchronous composite power angle graph of the synchronous motor. Compared with the graphs displayed by conventional power angle meters, the present invention can additionally display the following mechanical models: the rigid bodies of rotor and stator of the synchronous motor, the levers and springs of rotor and stator of the synchronous motor, and etc.

2. Compared with the electric vector graph of the synchronous motor, the composite power angle graph of the synchronous motor, which is depicted for measuring the operating state of the synchronous motor by the present invention, adds mechanical model graphs of the synchronous motor and also adds the assistant lines of E_qM and E_dN, is easier to illustrate the power distribution, active and reactive components of stator voltage, active and reactive components of stator current, and active and reactive components of spring pull of the synchronous motor, and can also illustrate the magnitude of the variance of the magnetic excitation adjustment signal.

3. The motor operating state graphs depicted for measuring the operating state of the synchronous motor by using the composite power angle meter of the present invention are advantageous for operators of various specialties to dialectically understand the operation principle of the synchronous motor from both electric and mechanical aspects, provide intuitional models for mechanical analysis of parallel-network operating state of the synchronous motor, and may be effective tools for the magnetic excitation characteristics analysis, magnetic excitation adjustment,

synchronous parallel-network, and operation monitoring and controlling of the synchronous motor.

4. The synchronous power angle graph of the synchronous motor depicted by the present invention may be applied in synchronous parallel-network monitoring of the synchronous motor.

5. The end composite magnetic leakage graph of the synchronous motor depicted by the present invention may be applied to analyze and monitor the end heat-emitting condition of the synchronous motor.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram illustrating the configuration of the composite power angle meter according to the present invention;

Figure 2 is a diagram illustrating the external connection relationship of the composite power angle meter according to the present invention;

Figure 3 is a diagram illustrating the operation principle of the I/V converting circuit of the composite power angle meter according to the present invention;

Figure 4 is a diagram illustrating a detailed circuitry of the data collection part of the composite power angle meter according to the present invention;

Figure 5 is a composite power angle graph depicted for measuring the operating state of a salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 6 is an electric power angle vector graph, namely sub-figure I of the composite power angle graph depicted for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 7 is a motor mechanical model graph, namely sub-figure II of the composite power angle graph depicted for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 8 is a motor mechanical model schematic graph, namely

sub-figure III of the composite power angle graph depicted for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 9 is a synchronous composite power angle graph, namely sub-figure IV of the composite power angle graph depicted for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 10 shows a coordinates model of the power angle graph of the salient-pole synchronous motor, which is established for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 11 is a diagram illustrating the digital symbols of the synchronous motor;

Figure 12 is a graph illustrating curves of a zero load and a zero power factor of a dynamotor;

Figure 13 is a graph illustrating the relationship between the air gap potential and the saturated reactance of the dynamotor;

Figure 14 is a composite power angle graph depicted for measuring the operating state of a non-salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 15 is an electric power angle vector graph, namely sub-figure I of the composite power angle graph depicted for measuring the operating state of the non-salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 16 is a motor mechanical model graph, namely sub-figure II of the composite power angle graph depicted for measuring the operating state of the non-salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 17 is a motor mechanical model schematic graph, namely sub-figure III of the composite power angle graph depicted for measuring the operating state of the non-salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 18 is a synchronous composite power angle graph, namely sub-figure IV of the composite power angle graph depicted for measuring the operating state of the non-salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 19 shows a coordinates model of the power angle graph of the non-salient-pole synchronous motor, which is established for measuring the operating state of the non-salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 20 is a motor-end composite magnetic leakage graph depicted for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 21 shows a motor-end composite magnetic leakage coordinates model established for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter according to the present invention;

Figure 22 is a motor-end composite magnetic leakage graph depicted for measuring the operating state of the non-salient-pole synchronous motor by using the composite power angle meter according to the present invention; and

Figure 23 shows a motor-end composite magnetic leakage coordinates model established for measuring the operating state of the non-salient-pole synchronous motor by using the composite power angle meter according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As shown in Figure 1, the composite power angle meter of the present invention consists of a data collection part 1 and a computer equipment 2. The data collection part 1 performs electric signal collecting and digital signal collecting. The electric signal collecting adopts an I/V converting circuit and an A/D conversion chip, the function of which is to collect various electric signals regarding the synchronous motor, convert the electric signals into digital signals, and transfer the digital

signals to the computer 2. The digital signal collecting collects digital signals of related equipments and transfers them to the computer 2. The host computer 2 stores an image displaying program and a computing program. According to the computing program, the host computer 2 performs computing on the related parameters of the synchronous motor to obtain the coordinates of related points and related data of the image, and inputs the results into the displaying program. The computer processes the coordinates of main points and the calculation results by the displaying program, displays on a display of the computer an electric model graph, a mechanical model graph and a dynamic composite power angle graph which vary with the motor's parameters and represent the operating state of the synchronous motor as well as the end composite magnetic leakage graph of the synchronous motor, and realizes the alarm function.

As shown in Figure 2, the composite power angle meter of the present invention is connected with the measuring devices of the electric power system through wires, and receives the electric signals outputted from the synchronous motor and the measuring devices of the electric power system (i.e. transducers), as listed in Table 1. When the electric power system may provide usable digital signals, the corresponding electric signal collecting circuit may be omitted, and the corresponding parameters can be obtained by the digital signal collecting.

Table 1: Electric signals received by and outputted from electric parameter transducers

Transducer	Received signal		Outputted signal
	Signal source	Electric signal	
DC voltage transducer	Synchronous motor exit TV1	Motor-end three phase line voltage U_{AB} U_{BC} U_{CA}	Motor-end three phase line voltage u_{AB} u_{BC} u_{CA}
	System TV2	System three phase line voltage U_{XAB} U_{XBC} U_{XCA}	System three phase line voltage u_{XAB} u_{XBC} u_{XCA}

	Synchronous motor exciter	Magnetic excitation voltage, and operating excitation voltage and backup excitation voltage thereof U_L U_G U_B	Magnetic excitation voltage, and operating excitation voltage and backup excitation voltage thereof u_L u_G u_B
	Switch state signal, switching off low potential, switching on high potential	Magnetic excitation system and synchronous motor exit switch state signal U_{ZG} U_{ZB} U_{DL}	Magnetic excitation system and synchronous motor exit switch state signal u_{ZG} u_{ZB} u_{DL}
	Exciter adjustment unit	Magnetic excitation adjustment signal U_1 U_2 ... U_n	Magnetic excitation adjustment signal u_1 u_2 ... u_n
DC current transducer	synchronous motor exciter	Magnetic excitation current, and operating excitation current and backup excitation current thereof I_L I_G I_{BY}	Magnetic excitation current, and operating excitation current and backup excitation current thereof i_L i_G i_{BY}
AC voltage transducer	Synchronous motor exit TV1	Motor-end three phase line voltage U_{AB} U_{BC} U_{CA}	Motor-end three phase line voltage effective value U_{ab} U_{bc} U_{ca}
	System TV2	System three phase line voltage U_{XAB} U_{XBC} U_{XCA}	System three phase line voltage effective value U_{xab} U_{xbc} U_{xca}
AC current	Synchronous	Motro-end three	Motro-end three phase

transducer	motor exit TA	phase current I_A I_B I_C	current effective value I_a I_b I_c
Power transducer	Synchronous motor exit TV1	Motor-end line voltage U_{AB} U_{BC} U_{CA}	Synchronous motor active power P
	Synchronous motor exit TA	Motor-end current I_A I_B I_C	Synchronous motor reactive power Q
Frequency transducer	Synchronous motor exit TV1	Motor-end line voltage U_{AB}	Motor-end voltage frequency f
	System TV2	System line voltage U_{XAB}	System voltage frequency f_X
negative sequence voltage transducer	Synchronous motor exit TV1	Motor-end three phase line voltage U_{AB} U_{BC} U_{CA}	Synchronous motor negative sequence voltage U_F

The operation of the electric signal data collecting part of the composite power angle meter mainly comprises three steps of:

1. Receiving motor signals by various electric parameter transducers and converting the signals into analogue current signals of 0-±20mA.

2. Converting the current signals outputted from the electric parameter transducers into voltage signals of 0-±5V by the I/V converting circuit.

3. Inputting the voltage signals of 0-±5V to a data collecting interface card, A/D converting the signals into digital data and storing them in a memory of the computer. Figure 3 illustrates the operation principle of the I/V converting circuit. When the current signals outputted from the transducer pass through resistances R_1 and R_2, the voltage signals of 0-±5V across R_2 are transferred to an A/D conversion device.

4. Figure 4 is a diagram illustrating the operation principle of the A/D conversion device in the data collection system. The main technical requirements are:

a. obtaining the instantaneous values of the motor-end voltage and system voltage at the same time, and storing them in the memory of the computer to perform calculation;

That is, the A/D conversion device of the data collection system needs to input the motor-end three phase instantaneous line voltage u_{AB}, u_{BC}, u_{CA} and the system three phase instantaneous line voltage u_{XAB}, u_{XBC}, u_{XCA} at the same time to the computer, and the computer performs calculation on each group of the instantaneous voltages.

b. The A/D conversion device may collect sufficient signals, and redundant samples may be used as the backup for temporary sampling increments.

The composite power angle meter digitizes the inputted electric signals by an A/D chip, and inputs the digitized signals to the host computer through COM or LPT. The host computer performs the computing program process and displaying program process on the inputted signals, and depicts the graph illustrating the operating state of the synchronous motor.

When the required calculation can be obtained from other equipments, the electric parameter collection circuit and the computing process may be omitted.

The method for measuring the operating state of the synchronous motor by using the composite power angle meter of the present invention comprises the steps of:

1. obtaining the stator voltage and current signals, magnetic excitation voltage and current signals, magnetic excitation adjustment signal, system voltage and current signals of the synchronous motor, as well as the state signals of the exit switch of the synchronous motor and its magnetic excitation circuit switch;

2. receiving the related digital signals and electric signals by the data collection part, digitizing the electric signals, and inputting the obtained digital signals to the host computer;

3. inputting the related parameters or commands to the host computer by keyboard and mouse;

4. performing calculation on the related parameters of the motor and performing the computing program process on the related data by the host computer; after the computing program process, inputting the obtained data to the displaying program to determine

instantaneous coordinates of the main points;

5. using the coordinates of the main points to depict various electric and mechanical model graphs of the synchronous motor through the displaying program process by the host computer, and displaying on the display a dynamic composite power angle graph of the synchronous motor and the end composite magnetic leakage graph of the synchronous motor which vary with the motor's parameters.

In terms of different shapes of the motor rotor, synchronous motors may be classified as two classifications of salient-pole synchronous motors and non-salient-pole synchronous motors. Accordingly, composite power angle meters of synchronous motor may be classified as composite power angle meters of salient-pole synchronous motor and composite power angle meters of non-salient-pole synchronous motor.

With reference to the different types of synchronous motors, the methods for measuring the different types of motors by using the composite power angle meters will now be described in detail.

I. The method for measuring the operating state of the salient-pole synchronous motor by using the composite power angle meter comprises steps of:

1. Obtaining the stator voltage and current signals, magnetic excitation voltage and current signals, magnetic excitation adjustment signal and system voltage signal of the synchronous motor as well as the state signals of the exit switch of the synchronous motor and its magnetic excitation circuit switch through the external wires of the composite power angle meter.

2. Converting the related electric signals into digital signals through the A/D conversion chip of the data collection part of the composite power angle meter, inputting the chip-converted digital signals and the received digital signals to the host computer through COM or LPT, and performing program process on the inputted signals by the computer.

3. Inputting the related parameters or commands to the host computer by keyboard and mouse.

4. Performing the program process on the above data by the host computer.

The program process comprises two parts of displaying program and computing program, the gist of which are listed below:

1) The gist of the displaying program

(1) Establishing image coordinates

The composite power angle meter of the salient-pole synchronous motor can display six kinds of graphs, which respectively are: composite power angle graph of salient-pole synchronous motor, as shown in Figure 5; electric power angle vector graph, namely sub-figure I of the composite power angle graph of the salient-pole synchronous motor, as shown in Figure 6; motor mechanical model graph, namely sub-figure II of the composite power angle graph of the salient-pole synchronous motor, as shown in Figure 7; motor mechanical model schematic graph, namely sub-figure III of the composite power angle graph of the salient-pole synchronous motor, as shown in Figure 8; synchronous composite power angle graph, namely sub-figure IV of the composite power angle graph of the salient-pole synchronous motor, as shown in Figure 9; motor-end composite magnetic leakage graph of the salient-pole synchronous motor, as shown in Figure 20. In accordance with Figures 5, 6, 7, 8 and 9, the coordinates-model is established by using the data to be required, as shown in Figure 10. In accordance with Figure 20, the coordinates-model is established by using the data to be required, as shown in Figure 21.

The letters of coordinate points of Figure 5 are tabbed by 0 at the lower right corner, the letters of coordinate points of Figure 6 are tabbed by 1 at the lower right corner, the letters of coordinate points of Figure 7 are tabbed by 2 or 3 at the lower right corner, the letters of coordinate points of Figure 8 are tabbed by 4 at the lower right corner, the letters of coordinate points of Figure 9 are tabbed by 5 at the lower right corner, and the letters of coordinate points of Figure 20 are tabbed by 20 at the lower right corner. The coordinates of the points are represented by the data to be required as follows:

Figure 5: $A_0(a, b)$, $B_0(c, d)$, $C_0(e, 0)$, $D_0(0, 0)$, $E_0(f, g)$, $F_0(f, 0)$, $G_0(c, 0)$;

Figure 6: $A_1(a, b)$, $C_1(e, 0)$, $D_1(0, 0)$, $E_1(f, g)$;

Figure 7: $A_2(\frac{a}{2}, \frac{b}{2})$, $B_2(\frac{c}{2}, \frac{d}{2})$, $C_2(\frac{e}{2}, 0)$, $D_2(0, 0)$, $E_2(\frac{f}{2}, \frac{g}{2})$, $A_3(-\frac{a}{2}, -\frac{b}{2})$, $B_3(-\frac{c}{2}, -\frac{d}{2})$, $C_3(-\frac{e}{2}, 0)$, $E_3(-\frac{f}{2}, -\frac{g}{2})$;

Figure 8: $A_4(a, b)$, $B_4(c, d)$, $C_4(e, 0)$, $D_4(0, 0)$, $E_4(f, g)$;

Figure 9: $A_5(h, i)$, $C_5(j, 0)$, $D_5(0, 0)$;

Figure 20: $T_{20}(0, 0)$, $X_{20}(X_1, Y_1)$, $Y_{20}(X_2, Y_2)$, $Z_{20}(X_3, Y_3)$.

Wherein, the power angle vector graph of the salient-pole synchronous motor as shown in Figure 6 is within the electric machine theory; the vector vertex of the synchronous motor magnetic excitation potential $\dot{E}_0$, as shown in Figure 6, has the same planar coordinates as points $A_0(a, b)$, $A_1(a, b)$ and $A_4(a, b)$; the vector vertex of the synchronous motor end voltage $\dot{U}$, as shown in Figure 6, has the same planar coordinates as points $C_0(e, 0)$, $C_1(e, 0)$ and $C_4(e, 0)$; the vector vertex O of the synchronous motor power angle, as shown in Figure 6, has the same planar coordinates as points $D_0(0, 0)$, $D_1(0, 0)$, $D_2(0, 0)$ and $D_4(0, 0)$; the coordinates value of point $A_2(\frac{a}{2}, \frac{b}{2})$ is half of the planar coordinates value of the vector vertex of the synchronous motor magnetic excitation potential $\dot{E}_0$ as shown in Figure 6; the coordinates value of point $C_2(\frac{e}{2}, 0)$ is half of the planar coordinates value of the vector vertex of the synchronous motor end voltage $\dot{U}$ as shown in Figure 6; the distance between point A_5 and point D_5 represents the synchronous end voltage of the synchronous motor, the distance between point C_5 and point D_5 represents the synchronous system voltage, and the angle δ as shown in Figure 9 is the phase angle difference between the synchronous motor voltage and the system voltage of synchronous time.

(2) The gist of imaging

a) The coordinate points in each figure only integrate with the present figure and only image in the present figure, the image moves smoothly, and when the synchronous motor stator current is not zero, the image of Figure 5 replaces the image of Figure 9.

b) The axial center of the rigid body of the synchronous motor rotor: depicting circles by taking points D_0, D_2, D_4 and D_5 respectively as the center of the circle and taking 1/20 of the length of the segment C_0D_0 obtained when the synchronous motor is under rating operation as the radius (the circles are in white).

c) The rigid body of the synchronous motor rotor: depicting

circles by taking points D_0, D_2, D_4 and D_5 respectively as the center of the circle and taking 1/4 of the length of the segment C_0D_0 obtained when the synchronous motor is under rating operation as the radius. The intersection portions of the rotor rigid body circles with the rotor rigid body axial center circles are still in white, and the rest portions are in dark blue.

d) The lever of the synchronous motor rotor: the lever is in dark blue (the same color as the rotor rigid body), and the line width of the lever is the same as the diameter of the axial center circle; when the rotor lever is a T-shaped lever, the length of the top beam of the T-shaped lever in each of Figures 5, 8 and 9 is two times as much as the length of the segment D_0C_0 obtained when the synchronous motor is under rating operation, and the top beam is central-positioned; the intersection portion of the lever with the rotor axial center is still in white. The length of the top beam of the T-shaped lever in Figure 7 is two times as much as the length of the segment D_2C_2 obtained when the synchronous motor is under rating operation, and the top beam is central-positioned; the intersection portion of the lever with the rotor axial center is still in white. The 1/2 length of the top beam must not be shorter than the length of the segment C_0E_0, C_2E_2 or C_4E_4 in respective figure.

Points D_0 and A_0, points A_3 and A_2, points D_4 and A_4 and points D_5 and A_5 are connected by levers respectively.

e) The stator rigid body: depicting a circle by taking point D_2 as the center of the circle and taking the 1/3 length of the segment C_0D_0 obtained when the synchronous motor is under rating operation as the radius. The portion out of the intersection portion of this circle with the rotor rigid body circle, the rotor axial center circle and the rotor lever is in light grey.

Points C_0 and D_0, points C_4 and D_4, and points C_5 and D_5 are connected by thin real line respectively, and at both ends of the segments there are prolongations as long as 1/2 length of the segment C_0D_0 obtained when the synchronous motor is under rating operation; the intersection portions with the rotor rigid body circle and the rotor axial center circle are represented by dotted lines; the part under the thin real line is shadowed with parallel thin-short bias, while the rotor rigid body circle and the rotor

axial center circle are not shadowed.

f) The stator lever: the stator lever is connected between points C_2 and C_3 with the same width as that of the rotor lever and the same color as that of the stator rigid body circle, and its intersection portion with the rotor rigid body circle and the rotor axial center circle is still in the color of the rotor rigid body circle and the rotor axial center circle.

Points C_0 and D_0, points C_4 and D_4, and points C_5 and D_5 are connected by black bold lines representing levers, the width of the bold line is the radius of the axial center circle, and its intersection portion with the rotor axial center circle and the rotor rigid body circle is represented by thin dotted line.

g) The spring: the spring is in black with realistic imaging; it is visualized to extend and shrink according to the lengthening and shortening of the spring; there ought to be an obvious joint between the spring and the lever.

Points B_0 and C_0, points E_0 and C_0, points B_2 and C_2, points E_2 and C_2, points B_3 and C_3, points E_3 and C_3, points B_4 and C_4, and points E_4 and C_4 are connected with springs respectively.

h) The joint between the spring and the lever: the joint between the spring and the lever is represented by a white circle, the diameter of the circle is slightly shorter than the diameter of the lever, the circle is positioned at the axial centers of the lever and the spring, and its connection with the spring is obviously visualized. The distances from the center of the circle on top of the lever representing the joint to both sides of the lever equal to the distances from the center to the ends of the lever.

i) The segments: points E_0 and F_0, points B_0 and G_0, and points C_0 and G_0 are connected by thin black lines respectively.

j) The vectors: linking points D_1 and A_1 by a segment with an arrow pointing to A_1; linking points E_1 and A_1 by a segment with an arrow pointing to A_1; linking points C_1 and E_1 by a segment with an arrow pointing to E_1; linking points D_1 and C_1 by a segment with an arrow pointing to C_1. Segment E_1A_1 is under segment D_1A_1. Points T_{20} and X_{20} are linked by a black bold segment with an arrow pointing to X_{20}; points T_{20} and Y_{20} are linked by a black bold segment with an arrow pointing to Y_{20}; points T_{20} and Z_{20} are linked by a colorful

bold segment with an arrow pointing to Z_{20}; points X_{20} and Z_{20} and points Y_{20} and Z_{20} are linked by black thin dotted segments respectively.

k) The marks of the coordinate points:

Point A_0 for "E_0", point B_0 for "E_d", point C_0 for "U", point D_0 for "O", point E_0 for "E_q", point F_0 for "M", and point G_0 for "N";

Point A_1 upper for "$\dot{E}_0$", lower for "$\dot{E}_d$", point C_1 for "$\dot{U}$", point D_1 for "O", and point E_1 for "$\dot{E}_q$";

Point A_2 for "$\Sigma\dot{\Phi}_0$", point B_2 for "$\Sigma\dot{\Phi}_d$", point C_2 for "$\Sigma\Sigma\dot{\Phi}$", point D_2 for "O", and point E_2 for "$\Sigma\dot{\Phi}_q$";

Point A_4 for "$\Sigma\dot{\Phi}_0$", point B_4 for "$\Sigma\dot{\Phi}_d$", point C_4 for "$\Sigma\Sigma\dot{\Phi}$", point D_4 for "O", and point E_4 for "$\Sigma\dot{\Phi}_q$";

Point A_5 for "E_0", point C_5 for "U", and point D_5 for "O"; and

Points X_{20}, Y_{20} and Z_{20} for "$\Sigma\dot{\Phi}_{0o}$", "$\Sigma\dot{\Phi}_{ao}$" and "$\Sigma\dot{\Phi}_{Do}$" respectively.

The marks move with the moving of the positions of the coordinate points, and the relative positions of the marks and corresponding coordinate points keep constant.

l) The power angle marks: the dotted line representing the power angle passes through the center of the rotor, superposing the axial center of the lever, and being not longer than 1/3 of the length of segment C_0D_0 obtained when the synchronous motor is under rating operation. It is marked as "δ" within the range of the power angle, the levers at both sides of the power angle are connected by an arc, the vertex of the arc varies as the positions of the levers vary, the radius of the arc is longer than the radius of the rotor rigid body circle, and the center of the arc superposes the stator axial center.

m) The magnetic excitation adjustment signal marks:

Two methods:

(a) In accordance with the abrupt change algorithm, depending on the length percentage by which ΔE_0 takes the present magnetic excitation potential, when ΔE_0 is greater than a given value it reveals the abrupt change of the magnetic excitation

potential; when ΔE_0 is positive, the adjustment signals are arranged from the top of the magnetic excitation lever to the rotor axial center, and when ΔE_0 is negative, the adjustment signals are arranged from the rotor axial center along the reverse direction of the magnetic excitation potential. On the displaying screen shown in Figure 5, the adjustment signals and their colors are marked.

(b) In accordance with the adjustment algorithm and the calculation results of the computer, by the values of E_{01}, E_{02} ... E_{0n}, the adjustments are represented with different colors and arranged depending on the length percentages they take; the increment-adjustment signals are closely arranged from the top of the magnetic excitation lever to the rotor axial center in sequence, and the reduction-adjustment signals are linearly and closely arranged from the rotor axial center along the reverse direction of the magnetic excitation potential in sequence, as shown in Figure 5. On the displaying screen shown in Figure 5, the adjustment signals and their colors are marked.

n) The PQ curve mark: as shown in Figure 10, determining the curve between points M_0 and N_0 according to the end heat-emitting limit of the synchronous motor and the greatest operation power angle of the synchronous motor that the system permits, determining the N_0O_0 curve according to the greatest active power that the synchronous motor permits, determining the O_0P_0 curve according to the greatest stator magnetic flux, the greatest stator current and the greatest stator potential that the synchronous motor permits, and determining the P_0Q_0 curve according to the greatest rotor magnetic flux, the greatest rotor current and the greatest rotor voltage that the synchronous motor permits. Points M_0 and Q_0 are both on the line D_0G_0, and points G_0 and Q_0 are connected by a thin line. Curve $M_0N_0O_0P_0Q_0$ (exclusive of the linear segment M_0Q_0) is depicted by a bold real line, the color of which is determined according to the user's requirement.

o) The composite magnetic leakage alarm circle: depicting a circle by taking T_{20} as the center of the circle and taking the greatest magnetic leakage flux that the synchronous motor permits as the radius; this circle is the alarm circle, which is represented by a colorful bold curve.

p) The synchronous image requirements: depicting dotted circles by taking point D_5 as the center of the circle and taking segments D_5A_5 and D_5C_5 as the radius respectively. When $\frac{d\bar{\delta}_x}{dt}$ is so big that the position of the lever D_5A_5 cannot be distinguished, the lever scanning portion outside the motor rotor rigid body is covered by misty light blue; when $\frac{d\bar{\delta}_x}{dt}$ is so small that the position of the lever D_5A_5 can be distinguished, it can be represented by the graph shown in Figure 9.

Q) The mechanical model as shown in Figure 7 may rotate anticlockwise dynamically, the ratio of the rotation speed of the model and that of the real object is marked on the screen, and the rotation speed ratio may be selected.

R) The image alarm display: when an alarm is given on electric parameters or magnetic flux, the marks turn to red flickers, the speaker of the computer whistles, and the corresponding segments in the composite power angle graph and its sub-figures turn to red flickers; and when the alarm is relieved, the alarm marks or segments stay red but without flicker. When alarms are given on various parameters, the corresponding alarm segments shown in Figure 10 can be referred to Table 2, and the images corresponding to the composite power angle graph or its sub-figures give alarms with red flickers; and when the alarms are relieved, the alarm images stay red but without flicker. When a parameter is clicked by the mouse, the corresponding segment shown in Figure 10 turns to the alarm color (with reference to Table 2), and the images corresponding to the composite power angle graph and its sub-figures turn red. When an alarm is given on magnetic leakage, segment $T_{20}Z_{20}$ turns red, and mark $\Sigma\dot{\Phi}_{D\sigma}$ turns red.

Table 2 Alarm table of the composite power angle graph of the salient-pole synchronous motor

Alarm parameter	Composite power angle graph	Composite power angle graph sub-figure I	Composite power angle graph sub-figure II	Composite power angle graph sub-figure III	Composite power angle graph sub-figure IV

Synchronous motor end voltage U_{ab} U_{bc} U_{ca}	D_0C_0	D_1C_1			D_5A_5 (T-shaped lever)
Synchronous motor stator composite magnetic flux	D_0C_0		C_2C_3	D_4C_4	D_5A_5 (T-shaped lever)
Synchronous motor magnetic excitation voltage and current u_L i_L	D_0A_0 (T-shaped lever)	D_1A_1			D_5A_5 (T-shaped lever)
Synchronous motor rotor magnetic flux	D_0A_0 (T-shaped lever)		A_2A_3 (I-shaped lever)	D_4A_4 (T-shaped lever)	D_5A_5 (T-shaped lever)
System voltage U_{xab} U_{xbc} U_{xca}					D_5C_5
Synchronous motor stator current I_a I_b I_c	E_0C_0 and C_0B_0				
Synchronous motor active	E_0F_0 and B_0G_0				

power P					
Synchronous motor reactive power Q	F_0C_0 and C_0G_0				

s) The digital mark display image: depicting the primary graph of the motor as shown in Figure 11, marking the displayed letters, displaying corresponding data of the displayed letters after the letters; the actual value and the per-unit value may be switched; when an alarm is given, the marks and numbers turn to red flickers, and the speaker of the computer whistles, and when the alarm is relieved, the marks and numbers stay red but without flicker. The conditions of displaying the marks and numbers are:

(a) After the parallel-network of the synchronous motor, namely when a motor exit breaker DL shuts on, the state signal U_{DL} of the motor exit breaker DL is at high level, the motor exit breaker DL turns blue, and the digital display image does not display the letter-marks and numbers of the voltage (U_{xab} U_{xbc} U_{xca}) and frequency (f_X) at the system side, while displaying other marks and numbers.

(b) During the parallel-off or the parallel-network of the synchronous motor, namely when the motor exit breaker DL shuts off, the state signal U_{DL} of the motor exit breaker DL is at low level, and the mark of the motor exit breaker DL turns white and displays all the marks and numbers.

(c) When an operating excitation switch or a backup excitation switch of the synchronous motor turns on, its state signal U_{ZG} or U_{ZB} is at high level, and the corresponding switch turns blue; when the magnetic excitation switch turns off, its state signal U_{ZG} or U_{ZB} is at low level, and the mark of the corresponding switch turns white.

(d) When the synchronous motor exit breaker DL shuts off, the digital display value of the synchronous motor rotor magnetic flux $\Sigma\Phi_0$ is made equal to the value of the total stator magnetic flux $\Sigma\Sigma\Phi$. When the synchronous motor exit breaker DL shuts on, the

calculation value is displayed as the value of the synchronous motor rotor magnetic flux $\Sigma\Phi_0$.

In accordance with the afore-mentioned imaging requirements, the six graphs as shown in Figures 5, 6, 7, 8, 9 and 20 can be obtained through program process. These six graphs can be combined with each other according to the requirements of the user, and any one of the combined images can be further combined with the digital display image of Figure 11. Adjustments may be made within a small range on the stator radius and rotor radius, the axial center radius of the stator and of the rotor, the diameter of the lever and the spring joint radius of the synchronous motor, which are given in Figures 5, 7, 8 and 9; the models shown in Figures 5, 7, 8 and 9 may be made as various three-dimensional mechanical models; and the color of the models may be adjusted according to the requirements of the user.

2) Gist of the computing program

(1) Determination of the parameters

Given parameters: the leakage reactance X_σ of the motor stator (Potier reactance), quadrature-axis synchronous reactance X_q, synchronous motor voltage, current and frequency conversion coefficients K_U, K_I and K_ω, system voltage and frequency conversion coefficients K_{XU} and $K_{X\omega}$, active and reactive power conversion coefficients K_P, K_Q and K_m, the conversion coefficients K_L, K_{GL} and K_{BL} of the magnetic excitation voltage and the operating excitation voltage and backup excitation voltage of the synchronous motor, the conversion coefficients K_f, K_{Gf} and K_{Bf} of the magnetic excitation current and the operating excitation current and backup excitation current of the synchronous motor, negative sequence voltage conversion coefficient K_F, the synchronous conversion coefficients K_T and K_N of the synchronous motor end voltage, the synchronous conversion coefficients K_{XT} and K_{XN} of the system voltage, the conversion coefficient K_{TJ} of the

voltage of the magnetic excitation adjustment signal, and magnetic flux leakage coefficients K_1, K_2 and K_3. Allowable range of main parameters: main parameters comprise motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power, stator magnetic flux, rotor magnetic flux, power angle, system voltage and so on. Rating parameters of the motor mainly comprise: motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power, stator magnetic flux, rotor magnetic flux, system voltage and so on.

(2) Calculation of the parameters

a) $P_j = K_P P$, $\Sigma P = K_m P_j$

b) $Q_j = K_Q Q$, $\Sigma Q = K_m Q_j$

c) $I_{aj} = K_I I_a$, $I_{bj} = K_I I_b$, $I_{cj} = K_I I_c$

d) $U_{abj} = K_U U_{ab}$, $U_{bcj} = K_U U_{bc}$, $U_{caj} = K_U U_{ca}$

e) $I_f = K_f i_L$, $I_{Gf} = K_{Gf} i_G$, $I_{Bf} = K_{Bf} i_{BY}$

f) $F = K_\omega f$, $F_X = K_{X\omega} f_X$

g) $U_{Fj} = K_F U_F$

h) $U_{xabj} = K_{XU} U_{xab}$, $U_{xbcj} = K_{XU} U_{xbc}$, $U_{xcaj} = K_{XU} U_{xca}$

i) $u_{Lj} = K_L u_L$, $u_{Gj} = K_{GL} u_G$, $u_{Bj} = K_{BL} u_B$

(3) Determination of the value of the direct-axis synchronous reactance X_d of the salient-pole synchronous motor

Two methods for determining the value of the direct-axis synchronous reactance X_d of the salient-pole synchronous motor are:

a) Directly determining the value of the direct-axis synchronous reactance X_d in accordance with the air gap potential E_δ obtained when the synchronous motor is under normal operation, and the value of X_d being kept constant.

b) Determining the value of X_d through the value of E_δ in accordance with the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d, and comprising the steps of:

(a) Recording the dynamotor zero load ($I_a = 0$) curve and the zero power factor ($I_a = I_N$) curve as shown in Figure

12, namely curve $U=f_0(I_f)$ and curve $U=f_N(I_f)$.

(b) Determining the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d.

In accordance with the curves $U=f_0(I_f)$ and $U=f_N(I_f)$, taking n magnetic excitation current values of I_{f1}, I_{f2} … I_{fn}, and determining on the curve $U=f_N(I_f)$ points B_1, B_2 … B_n corresponding to I_{f1}, I_{f2} … I_{fn} based on the zero power factor curve. Constructing n congruent triangles through points B, B_1, B_2 … B_n respectively (wherein segment CD is vertical to the I-coordinate, and $CD = I_N * X_\sigma$), intersecting with the zero load characteristic curve of $U= f_0(I_f)$ at points C, C_1, C_2, … C_n respectively, connecting points O and C_1, and extending segment OC_1 to intersect with the line that passes through point B_1 and is parallel to the U-coordinate at point A_1; similarly, connecting points O and C_2, … connecting points O and C_n, and extending segment OC_2 … extending OC_n, and intersecting with the lines that pass through points B_2 … B_n respectively and are parallel to the U-coordinate at points A_2 … A_n respectively.

Therefore, the synchronous saturated reactance corresponding to $E_{\delta 1}$, $E_{\delta 2}$ … $E_{\delta n}$ respectively are: $X_{d1} = \frac{A_1B_1}{I_N}$, $X_{d2} = \frac{A_2B_2}{I_N}$ … $X_{dn} = \frac{A_nB_n}{I_N}$. Depicting the relationship graph of the air gap potential and the reactance in accordance with the relationship between $E_{\delta 1}$, $E_{\delta 2}$ … $E_{\delta n}$ and respective corresponding synchronous saturated reactance X_{d1}, X_{d2} … X_{dn}, as shown in Figure 13. The function $X_d= f(E_\delta)$ can be determined by this curve.

(c) Computing E_δ.

Let $\dot{W} = P_j + jQ_j = W\angle\varphi$; $\dot{U}_a = \frac{U_{ab}}{\sqrt{3}} = e$;

Then $\dot{I}_{aj} = I_{aj}\angle(-\varphi)$,

$$\dot{E}_\delta = e + j\dot{I}_{aj} * X_\sigma; \quad E_\delta = |\dot{E}_\delta|$$

(d) Substituting the value of E_δ into function $X_d=$

$f(E_\delta)$ to obtain the value of X_d.

(4) Calculations

a) $\dot{H} = e + j\dot{I}_{aj} * X_q = H\angle\delta$ $\delta(90°\rangle\delta\rangle - 90°)$ can be determined by this equation

b) $I_d = I_{aj}\sin(\delta + \varphi)$

c) $I_q = I_{aj}\cos(\delta + \varphi)$

d) $a = (e * \cos\delta + I_d * X_d) * \cos\delta$

e) $b = (e * \cos\delta + I_d * X_d) * \sin\delta$

f) $c = e + I_d * X_d * \cos\delta$

g) $d = I_d * X_d * \sin\delta$

h) $f = e * \cos^2\delta$

i) $g = \frac{1}{2} e * \sin 2\delta$

j) Calculations of components of the magnetic excitation

Two calculation methods are:

(a) Abrupt change algorithm

Assuming the average magnetic excitation potential of the synchronous motor during the period of ΔT from some certain time till now as ΣE_0, and the current magnetic excitation potential being E_0; assuming $\Delta E_0 = E_0 - \Sigma E_0$. The value of ΔT and the times of sampling the magnetic excitation potential may be set.

(b) Adjustment algorithm

Assuming the total automatic magnetic excitation adjustment of the integrated amplifier as ΣU; the components respectively are: $\Delta U = K_{TJ} U_1$, $U' = K_{TJ} U_2$, $\Delta f = K_{TJ} U_3$ $\cdots X = K_{TJ} U_n$; $\Sigma U = K_{TJ}(U_1 + U_2 + \cdots + U_n)$, $f_1 = \frac{K_{TJ} U_1}{\Sigma U}$, $f_2 = \frac{K_{TJ} U_2}{\Sigma U}$ ... $f_n = \frac{K_{TJ} U_n}{\Sigma U}$

Calculating $E_{01} = f_1\sqrt{a^2 + b^2}$, $E_{02} = f_2\sqrt{a^2 + b^2}$ ... $E_{0n} = f_n\sqrt{a^2 + b^2}$

k) Calculation of coordinates of the magnetic flux leakage

$X_1 = K_1 a$; $Y_1 = K_1 b$; $X_2 = K_2(f-a) + K_3(c-a)$; $Y_2 = K_2(g-b) + K_3(d-b)$; $X_3 = X_1 + X_2$; $Y_3 = Y_1 + Y_2$

l) Calculation of the per-unit value of the magnetic flux: assuming when the frequency is at the rating value, the per-unit value of a certain magnetic flux of the synchronous motor

equals to the per-unit value of the corresponding voltage; determining the per-unit values of the magnetic excitation flux and the stator total magnetic flux of the motor according to the relationship among frequency, voltage and magnetic flux, and displaying the per-unit values with digitals; comparing the calculated values with the given values, and alarming when the calculated values are larger than the given values.

m) Calculations of the per-unit values of various parameters according to the requirements.

(5) During the synchronous parallel-network or parallel-off, namely when $I_a = I_b = I_c = 0$, performing the following calculations on each set of the synchronous motor voltage and the system voltage inputted to the computer:

(a) $\dot{U} = K_T(u_{AB} + u_{BC}\angle 120^0 + u_{CA}\angle 240^0) = U\angle\alpha$

(b) $\dot{U}_x = K_{XT}(u_{XAB} + u_{XBC}\angle 120^0 + u_{XCA}\angle 240^0) = U_x\angle\varepsilon$

(c) $\frac{\dot{U}}{\dot{U}_x} = \frac{U}{U_x}\angle\delta_x$

(d) $\overline{\delta}_x = \frac{\delta_1+\delta_2+\cdots\delta_n}{n}$ (wherein $\delta_1\delta_2\cdots\delta_n$ are the values of the first, the second ⋯ and the n^{th} δ_x measured within a certain time period; when a second measured value enters, the value of the first δ_1 is abandoned, and when the next measured value enters, the value of the second δ_2 is abandoned; analogically, the new measured values replace the old ones; and the time period and the value of n can be set.)

(e) $h = K_N U_{abj} * \cos\overline{\delta}_x$

(f) $i = K_N U_{abj} * \sin\overline{\delta}_x$

(g) $j = K_{XN} U_{xabj}$

(6) Comparing various electric parameters with respective given values, and alarming when the electric parameters are out of the prescribed ranges.

II. The method for measuring the operating state of the non-salient-pole synchronous motor by using the non-salient-pole composite power angle meter comprises steps of:

1. Obtaining the stator voltage and current signals, magnetic excitation voltage and current signals, magnetic excitation adjustment signal and system voltage signal of the synchronous

motor as well as the state signals of the exit switch of the synchronous motor and its magnetic excitation circuit switch through the external wires of the composite power angle meter.

2. Converting the related electric signals into digital signals through the A/D conversion chip of the data collection part of the composite power angle meter, inputting the chip-converted digital signals and the received digital signals to the host computer through COM or LPT, and performing program process on the inputted signals by the computer.

3. Inputting the related parameters or commands to the host computer by keyboard and mouse.

4. Performing the program process on the above data by the host computer.

The program process comprises two parts of displaying program and computing program, the gist of which are listed below:

1) The gist of the displaying program

(1) Establishing image coordinates

The composite power angle meter of the non-salient-pole synchronous motor can display six kinds of graphs, which respectively are: composite power angle graph of non-salient-pole synchronous motor, as shown in Figure 14; electric power angle vector graph, namely sub-figure I of the composite power angle graph of the non-salient-pole synchronous motor, as shown in Figure 15; motor mechanical model graph, namely sub-figure II of the composite power angle graph of the non-salient-pole synchronous motor, as shown in Figure 16; motor mechanical model schematic graph, namely sub-figure III of the composite power angle graph of the non-salient-pole synchronous motor, as shown in Figure 17; synchronous composite power angle graph, namely sub-figure IV of the composite power angle graph of the non-salient-pole synchronous motor, as shown in Figure 18; motor-end composite magnetic leakage graph of the non-salient-pole synchronous motor, as shown in Figure 22. In accordance with the common characteristics of these figures, the coordinates-model is established by using the data to be required, as shown in Figure 19. In accordance with the characteristic of Figure 22, the coordinates-model is established by using the data to be required, as shown in Figure 23. The letters of coordinate points of Figure 14 are tabbed by 10 at the

lower right corner, the letters of coordinate points of Figure 15 are tabbed by 11 at the lower right corner, the letters of coordinate points of Figure 16 are tabbed by 12 or 13 at the lower right corner, the letters of coordinate points of Figure 17 are tabbed by 14 at the lower right corner, the letters of coordinate points of Figure 18 are tabbed by 15 at the lower right corner, and the letters of coordinate points of Figure 22 are tabbed by 22 at the lower right corner. The coordinates of the points are represented by the data to be required as follows:

Figure 14: $A_{10}(a, b)$, $C_{10}(e, 0)$, $D_{10}(0, 0)$, $G_{10}(a, 0)$;

Figure 15: $A_{11}(a, b)$, $C_{11}(e, 0)$, $D_{11}(0, 0)$;

Figure 16: $A_{12}(\frac{a}{2}, \frac{b}{2})$, $C_{12}(\frac{e}{2}, 0)$, $D_{12}(0, 0)$, $A_{13}(-\frac{a}{2}, -\frac{b}{2})$, $C_{13}(-\frac{e}{2}, 0)$;

Figure 17: $A_{14}(a, b)$, $C_{14}(e, 0)$, $D_{14}(0, 0)$;

Figure 18: $A_{15}(h, i)$, $C_{15}(j, 0)$, $D_{15}(0, 0)$;

Figure 22: $T_{22}(0, 0)$, $X_{22}(X_1, Y_1)$, $Y_{22}(X_2, Y_2)$, $Z_{22}(X_3, Y_3)$.

Wherein, the power angle vector graph of the non-salient-pole synchronous motor as shown in Figure 15 is within the electric machine theory; the vector vertex of the synchronous motor magnetic excitation potential $\dot{E}_0$, as shown in Figure 15, has the same planar coordinates as points $A_{10}(a, b)$, $A_{11}(a, b)$ and $A_{14}(a, b)$; the vector vertex of the synchronous motor end voltage $\dot{U}$, as shown in Figure 15, has the same planar coordinates as points $C_{10}(e, 0)$, $C_{11}(e, 0)$ and $C_{14}(e, 0)$; the vector vertex O of the synchronous motor power angle, as shown in Figure 15, has the same planar coordinates as points $D_{10}(0, 0)$, $D_{11}(0, 0)$, $D_{12}(0, 0)$ and $D_{14}(0, 0)$; the coordinates value of point $A_{12}(\frac{a}{2}, \frac{b}{2})$ is half of the planar coordinates value of the vector vertex of the synchronous motor magnetic excitation potential $\dot{E}_0$ as shown in Figure 15; the coordinates value of point $C_{12}(\frac{e}{2}, 0)$ is half of the planar coordinates value of the vector vertex of the synchronous motor end voltage $\dot{U}$ as shown in Figure 15; the distance between point A_{15} and point D_{15} represents the synchronous end voltage of the synchronous motor, the distance

between point C_{15} and point D_{15} represents the synchronous system voltage, and the angle δ as shown in Figure 18 is the phase angle difference between the synchronous motor voltage and the system voltage of synchronous time.

(2) The gist of imaging

a) The coordinate points in each figure only integrate with the present figure and only image in the present figure, the image moves smoothly, and when the synchronous motor stator current is not zero, the image of Figure 14 replaces the image of Figure 18.

b) The axial center of the rigid body of the synchronous motor rotor: depicting circles by taking points D_{10}, D_{12}, D_{14} and D_{15} respectively as the center of the circle and taking 1/20 of the length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation as the radius (the circles are in white).

c) The rigid body of the synchronous motor rotor: depicting circles by taking points D_{10}, D_{12}, D_{14} and D_{15} respectively as the center of the circle and taking 1/5 of the length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation as the radius. The intersection portions of the rotor rigid body circles with the rotor rigid body axial center circles are still in white, and the rest portions are in dark blue.

d) The lever of the synchronous motor rotor: the lever is in dark blue (the same color as the rotor rigid body), and the line width of the lever is the same as the diameter of the axial center circle; the intersection portion of the lever with the rotor axial center is still in white.

Points D_{10} and A_{10}, points A_{12} and A_{13}, points A_{14} and D_{14} and points A_{15} and D_{15} are connected by levers respectively.

e) The stator rigid body: depicting a circle by taking point D_{12} as the center of the circle and taking the 1/3 length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation as the radius. The portion out of the intersection portion of this circle with the rotor rigid body circle, the rotor axial center circle and the rotor lever is in light grey.

Points C_{10} and D_{10}, points C_{14} and D_{14}, and points C_{15} and D_{15} are connected by thin real line respectively, and at both ends of the segments there are prolongations as long as 1/2 length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating

operation; the intersection portions with the rotor rigid body circle and the rotor axial center circle are represented by dotted lines; the part under the thin real line is shadowed with parallel thin-short bias, while the rotor rigid body circle and the rotor axial center circle are not shadowed.

f) The stator lever: the stator lever is connected between points C_{12} and C_{13} with the same width as that of the rotor lever and the same color as that of the stator rigid body, and its intersection portion with the rotor rigid body circle and the rotor axial center circle is still in the color of the rotor rigid body circle and the rotor axial center circle.

Points C_{10} and D_{10}, points C_{14} and D_{14}, and points C_{15} and D_{15} are connected by black bold lines representing levers, the width of the bold line is the radius of the axial center circle, and its intersection portion with the rotor axial center circle and the rotor rigid body circle is represented by thin dotted line.

g) The spring: the spring is in black with realistic imaging; it is visualized to extend and shrink according to the lengthening and shortening of the spring; there ought to be an obvious joint between the spring and the lever.

Points A_{10} and C_{10}, points A_{12} and C_{12}, points A_{13} and C_{13}, and points A_{14} and C_{14} are connected with springs respectively.

h) The joint between the spring and the lever: the joint between the spring and the lever is represented by a white circle, the diameter of the circle is slightly shorter than the diameter of the lever, the circle is positioned at the axial centers of the lever and the spring, and its connection with the spring is obviously visualized. The distances from the center of the circle on top of the lever representing the joint to both sides of the lever equal to the distances from the center to the ends of the lever respectively.

i) The segments: points A_{10} and G_{10} and points C_{10} and G_{10} are connected by thin black lines respectively.

j) The vectors: linking points D_{11} and A_{11} by a segment with an arrow pointing to A_{11}; linking points D_{11} and C_{11} by a segment with an arrow pointing to C_{11}; linking points C_{11} and A_{11} by a segment with an arrow pointing to C_{11}. Points T_{22} and X_{22} are linked by a black bold segment with an arrow pointing to X_{22}; points T_{22}

and Y_{22} are linked by a black bold segment with an arrow pointing to Y_{22}; points T_{22} and Z_{22} are linked by a colorful bold segment with an arrow pointing to Z_{22}; points X_{22} and Z_{22} and points Y_{22} and Z_{22} are linked by black thin dotted segments respectively.

k) The marks of the coordinate points:

A_{10} for "E_0", point C_{10} for "U", point D_{10} for "O", and point G_{10} for "M";

Point A_{11} for "$\dot{E}_0$", point C_{11} for "$\dot{U}$", and point D_{11} for "O"; segment $A_{11}C_{11}$ for "$\dot{E}_a$";

Point A_{12} for "$\Sigma\dot{\Phi}_0$", point C_{12} for "$\Sigma\Sigma\dot{\Phi}$", and point D_{12} for "O";

Point A_{14} for "$\Sigma\dot{\Phi}_0$", point C_{14} for "$\Sigma\Sigma\dot{\Phi}$", and point D_{14} for "O";

Point A_{15} for "E_0", point C_{15} for "U", and point D_{15} for "O";

The marks of the magnetic leakage composite graph: points X_{22}, Y_{22} and Z_{22} for "$\Sigma\dot{\Phi}_{0\sigma}$", "$\Sigma\dot{\Phi}_{a\sigma}$" and "$\Sigma\dot{\Phi}_{D\sigma}$" respectively.

The marks move with the moving of the positions of the coordinate points, and the relative positions of the marks and corresponding coordinate points keep constant.

l) The power angle marks: the dotted line representing the power angle passes through the center of the rotor, superposing the axial center of the lever, and being not longer than 1/3 of the length of segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation. It is marked as "δ" within the range of the power angle, the levers at both sides of the power angle are connected by an arc, the vertex of the arc varies as the positions of the levers vary, the radius of the arc is longer than the radius of the rotor rigid body circle, and the center of the arc superposes the stator axial center.

m) The magnetic excitation adjustment signal marks:

Two methods:

(a) In accordance with the abrupt change algorithm, depending on the length percentage by which ΔE_0 takes the present magnetic excitation potential, when ΔE_0 is greater than a given value it reveals the abrupt change of the magnetic excitation potential; when ΔE_0 is positive, the adjustment signals are arranged from the top of the magnetic excitation lever to the rotor

axial center, and when ΔE_0 is negative, the adjustment signals are arranged from the rotor axial center along the reverse direction of the magnetic excitation potential. On the displaying screen shown in Figure 14, the adjustment signals and their colors are marked.

(b) In accordance with the adjustment algorithm and the calculation results of the computer, by the values of E_{01}, E_{02} ... E_{0n}, the adjustments are represented with different colors and arranged depending on the length percentages they take; the increment-adjustment signals are closely arranged from the top of the magnetic excitation lever to the rotor axial center in sequence, and the reduction-adjustment signals are linearly and closely arranged from the rotor axial center along the reverse direction of the magnetic excitation potential in sequence, as shown in Figure 14. On the displaying screen shown in Figure 14, the adjustment signals and their colors are marked.

n) The PQ curve mark: determining the curve between points M_{10} and N_{10} according to the end heat-emitting limit of the synchronous motor and the greatest operation power angle of the synchronous motor that the system permits, determining the $N_{10}O_{10}$ curve according to the greatest active power that the synchronous motor permits, determining the $O_{10}P_{10}$ curve according to the greatest stator magnetic flux, the greatest stator current and the greatest stator potential that the synchronous motor permits, and determining the $P_{10}Q_{10}$ curve according to the greatest rotor magnetic flux, the greatest rotor current and the greatest rotor voltage that the synchronous motor permits. Points M_{10} and Q_{10} are both on the line $D_{10}G_{10}$, and points G_{10} and Q_{10} are connected by a thin line. Curve $M_{10}N_{10}O_{10}P_{10}Q_{10}$ (exclusive of the linear segment $M_{10}Q_{10}$) is depicted by a bold real line, the color of which is determined according to the user's requirement.

o) The composite magnetic leakage alarm circle: depicting a circle by taking T_{22} as the center of the circle and taking the greatest magnetic leakage flux that the synchronous motor permits as the radius; this circle is the alarm circle, which is represented by a colorful bold curve.

p) The synchronous image requirements: depicting dotted circles by taking point D_{15} as the center of the circle and taking

segments $D_{15}A_{15}$ and $D_{15}C_{15}$ as the radius respectively. When $\frac{d\bar{\delta}_x}{dt}$ is so big that the position of the lever $D_{15}A_{15}$ cannot be distinguished, the lever scanning portion outside the motor rotor rigid body is covered by misty light blue; when $\frac{d\bar{\delta}_x}{dt}$ is so small that the position of the lever $D_{15}A_{15}$ can be distinguished, it can be represented by the graph shown in Figure 18.

q) The mechanical model as shown in Figure 16 may rotate anticlockwise dynamically, the ratio of the rotation speed of the model and that of the real object is marked on the screen, and the rotation speed ratio may be selected.

r) The image alarm display: when an alarm is given on electric parameters or magnetic flux, the marks turn to red flickers, the speaker of the computer whistles, and the corresponding segments in the composite power angle graph and its sub-figures turn to red flickers; and when the alarm is relieved, the alarm marks or segments stay red but without flicker. When alarms are given on various parameters, the corresponding alarm segments shown in Figure 19 can be referred to Table 3, and the images corresponding to the composite power angle graph or its sub-figures give alarms with red flickers; and when the alarms are relieved, the alarm images stay red but without flicker. When a parameter is clicked by the mouse, the corresponding segment shown in Figure 19 turns to the alarm color (with reference to Table 3), and the images corresponding to the composite power angle graph and its sub-figures turn red. When an alarm is given on magnetic leakage, segment $T_{22}Z_{22}$ turns red, and mark $\Sigma\dot{\Phi}_{D\sigma}$ turns red.

Table 3 Alarm table of the composite power angle graph of the non-salient-pole synchronous motor

Alarm parameter	Composite power angle graph	Composite power angle graph sub-figure I	Composite power angle graph sub-figure II	Composite power angle graph sub-figure III	Composite power angle graph sub-figure IV

Synchronous motor end voltage U_{ab} U_{bc} U_{ca}	$D_{10}C_{10}$	$D_{11}C_{11}$			$D_{15}A_{15}$
Synchronous motor stator composite magnetic flux	$D_{10}C_{10}$		$C_{12}C_{13}$	$D_{14}C_{14}$	$D_{15}A_{15}$
Synchronous motor magnetic excitation voltage and current u_L i_L	$D_{10}A_{10}$	$D_{11}A_{11}$			$D_{15}A_{15}$
Synchronous motor rotor magnetic flux	$D_{10}A_{10}$		$A_{12}A_{13}$	$D_{14}A_{14}$	$D_{15}A_{15}$
System voltage U_{xab} U_{xbc} U_{xca}					$D_{15}C_{15}$
Synchronous motor stator current I_a I_b I_c	$C_{10}A_{10}$				
Synchronous motor active	$A_{10}G_{10}$				

power P					
Synchronous motor reactive power Q	$C_{10}G_{10}$				

s) The digital mark display image: depicting the primary graph of the motor as shown in Figure 11, marking the displayed letters, displaying corresponding data of the displayed letters after the letters; the actual value and the per-unit value may be switched; when an alarm is given, the marks and numbers turn to red flickers, and the speaker of the computer whistles, and when the alarm is relieved, the marks and numbers stay red but without flicker. The conditions of displaying the marks and numbers are:

(a) After the parallel-network of the synchronous motor, namely when a motor exit breaker DL shuts on, the state signal U_{DL} of the motor exit breaker DL is at high level, the motor exit breaker DL turns blue, and the digital display image does not display the letter-marks and numbers of the voltage (U_{xab} U_{xbc} U_{xca}) and frequency (f_X) at the system side, while displaying other marks and numbers.

(b) During the parallel-off or the parallel-network of the synchronous motor, namely when the motor exit breaker DL shuts off, the state signal U_{DL} of the motor exit breaker DL is at low level, and the mark of the motor exit breaker DL turns white and displays all the marks and numbers.

(c) When an operating excitation switch or a backup excitation switch of the synchronous motor turns on, its state signal U_{ZG} or U_{ZB} is at high level, and the corresponding switch turns blue; when the magnetic excitation switch turns off, its state signal U_{ZG} or U_{ZB} is at low level, and the mark of the corresponding switch turns white.

(d) When the synchronous motor exit breaker DL shuts off, the digital display value of the synchronous motor rotor magnetic flux $\Sigma\Phi_b$ is made equal to the value of the total stator magnetic flux $\Sigma\Sigma\Phi$. When the synchronous motor exit breaker DL shuts on, the

calculation value is displayed as the value of the synchronous motor rotor magnetic flux $\Sigma\Phi_0$.

In accordance with the afore-mentioned imaging requirements, the six graphs as shown in Figures 14, 15, 16, 17, 18 and 22 can be obtained through program process. These six graphs can be combined with each other according to the requirements of the user, and any one of the combined images can be further combined with the digital display image of Figure 11. Adjustments may be made within a small range on the stator radius and rotor radius, the axial center radius of the stator and of the rotor, the diameter of the lever and the spring joint radius of the synchronous motor, which are given in Figures 14, 16, 17 and 18; the models shown in Figures 14, 16, 17 and 18 may be made as various three-dimensional mechanical models; and the color of the models may be adjusted according to the requirements of the user.

2) Gist of the computing program

(1) Determination of the parameters

Given parameters: the leakage reactance X_σ of the motor stator, synchronous motor voltage, current and frequency conversion coefficients K_U, K_I and K_ω, system voltage and frequency conversion coefficients K_{XU} and $K_{X\omega}$, active and reactive power conversion coefficients K_P, K_Q and K_m, the conversion coefficients K_L, K_{GL} and K_{BL} of the magnetic excitation voltage and the operating excitation voltage and backup excitation voltage of the synchronous motor, the conversion coefficients K_f, K_{Gf} and K_{Bf} of the magnetic excitation current and the operating excitation current and backup excitation current of the synchronous motor, the computing coefficient m of the synchronous motor, negative sequence voltage conversion coefficient K_F, the synchronous conversion coefficients K_T and K_N of the synchronous motor end voltage, the synchronous conversion coefficients K_{XT} and K_{XN} of the system voltage, the conversion coefficient K_{TJ} of the voltage of the magnetic excitation adjustment signal, and magnetic flux leakage

coefficients K_1 and K_2. Allowable range of main parameters: main parameters comprise motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power, stator magnetic flux, rotor magnetic flux, power angle and system voltage. Rating parameters of the motor mainly comprise: motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power, stator magnetic flux, rotor magnetic flux and system voltage.

(2) Calculation of the parameters

a) $P_j = K_P P$, $\Sigma P = K_m P_j$

b) $Q_j = K_Q Q$, $\Sigma Q = K_m Q_j$

c) $I_{aj} = K_I I_a$, $I_{bj} = K_I I_b$, $I_{cj} = K_I I_c$

d) $U_{abj} = K_U U_{ab}$, $U_{bcj} = K_U U_{bc}$, $U_{caj} = K_U U_{ca}$

e) $I_f = K_f i_L$, $I_{Gf} = K_{Gf} i_G$, $I_{Bf} = K_{Bf} i_{BY}$

f) $F = K_\omega f$, $F_X = K_{X\omega} f_X$

g) $U_{Fj} = K_F U_F$

h) $U_{xabj} = K_{XU} U_{xab}$, $U_{xbcj} = K_{XU} U_{xbc}$, $U_{xcaj} = K_{XU} U_{xca}$

i) $u_{Lj} = K_L u_L$, $u_{Gj} = K_{GL} u_G$, $u_{Bj} = K_{BL} u_B$

(3) Determination of the value of the direct-axis synchronous reactance X_d of the non-salient-pole synchronous motor

Two methods for determining the value of the direct-axis synchronous reactance X_d of the non-salient-pole synchronous motor are:

a) Directly determining the value of the direct-axis synchronous reactance X_d in accordance with the air gap potential E_δ obtained when the synchronous motor is under normal operation, and the value of X_d being kept constant.

b) Determining the value of X_d in accordance with the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d, and comprising the steps of:

(a) Recording the dynamotor zero load ($I_a = 0$) curve and the zero power factor ($I_a = I_N$) curve as shown in Figure 12, namely curve $U=f_0(I_f)$ and curve $U=f_N(I_f)$.

(b) Determining the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d.

In accordance with the curves $U=f_0(I_f)$ and $U=f_N(I_f)$, taking n magnetic excitation current values of I_{f1}, I_{f2} ... I_{fn}, and determining on the curve $U=f_N(I_f)$ points B_1, B_2 ⋯ B_n corresponding to I_{f1}, I_{f2} ... I_{fn} based on the zero power factor curve. Constructing n congruent triangles through points B, B_1, B_2 ⋯ B_n respectively (wherein segment CD is vertical to the I-coordinate, and $CD = I_N * X_\sigma$), intersecting with the zero load characteristic curve of $U= f_0(I_f)$ at points C, C_1, C_2, ⋯ C_n respectively, connecting points O and C_1, and extending segment OC_1 to intersect with the line that passes through point B_1 and is parallel to the U-coordinate at point A_1; similarly, connecting points O and C_2, ⋯ connecting points O and C_n, and extending segment OC_2 ⋯ extending OC_n, and intersecting with the lines that pass through points B_2 ⋯ B_n respectively and are parallel to the U-coordinate at points A_2 ⋯ A_n respectively.

Therefore, the synchronous saturated reactance corresponding to $E_{\delta 1}$, $E_{\delta 2}$ ... $E_{\delta n}$ respectively are: $X_{d1} = \frac{A_1 B_1}{I_N}$, $X_{d2} = \frac{A_2 B_2}{I_N}$ ... $X_{dn} = \frac{A_n B_n}{I_N}$. Depicting the relationship graph of the air gap potential and the reactance in accordance with the relationship between $E_{\delta 1}$, $E_{\delta 2}$ ... $E_{\delta n}$ and respective corresponding synchronous saturated reactance X_{d1}, X_{d2} ... X_{dn}, as shown in Figure 13. The function $X_d= f(E_\delta)$ can be determined by this curve.

(c) Computing E_δ.

Let $\dot{W} = P_j + jQ_j = W\angle\varphi$; $\dot{U}_a = \frac{U_{abj}}{\sqrt{3}} = e$;

Then $\dot{I}_{aj} = I_{aj}\angle(-\varphi)$,

$$\dot{E}_\delta = e + j\dot{I}_{aj} * X_\sigma;\quad E_\delta = |\dot{E}_\delta|$$

(d) Substituting the value of E_δ into function $X_d= f(E_\delta)$ to obtain the value of X_d.

(4) Calculations

a) $a = e + \frac{Q_J}{me} X_d$

b) $b = \frac{P_J}{me} X_d$

c) Calculations of components of the magnetic excitation

Two calculation methods are:

(a) Abrupt change algorithm

Assuming the average magnetic excitation potential of the synchronous motor during the period of ΔT from some certain time till now as ΣE_0, and the current magnetic excitation potential being E_0; assuming $\Delta E_0 = E_0 - \Sigma E_0$. The value of ΔT and the times of sampling the magnetic excitation potential may be set.

(b) Adjustment algorithm

Assuming the total automatic magnetic excitation adjustment of the integrated amplifier as ΣU; the components respectively are: $\Delta U = K_{TJ} U_1$, $U' = K_{TJ} U_2$, $\Delta f = K_{TJ} U_3$ $\cdots X = K_{TJ} U_n$; $\Sigma U = K_{TJ}(U_1+U_2+\cdots+U_n)$, $f_1 = \frac{K_{TJ} U_1}{\Sigma U}$, $f_2 = \frac{K_{TJ} U_2}{\Sigma U}$ ... $f_n = \frac{K_{TJ} U_n}{\Sigma U}$

Calculating $E_{01} = f_1 \sqrt{a^2 + b^2}$, $E_{02} = f_2 \sqrt{a^2 + b^2}$ ... $E_{0n} = f_n \sqrt{a^2 + b^2}$

d) Calculation of the per-unit value of the magnetic flux: assuming when the frequency is at the rating value, the per-unit value of a certain magnetic flux of the synchronous motor equals to the per-unit value of the corresponding voltage; determining the per-unit values of the magnetic excitation flux and the stator total magnetic flux of the motor according to the relationship among frequency, voltage and magnetic flux; comparing the calculated values with the given values, and alarming when the calculated values are larger than the given values.

e) comparing various electric parameters with respective given values, and alarming when the electric parameters are larger than the given values.

f) Calculation of the coordinates of the magnetic flux leakage

$X_1=K_1a$; $Y_1=K_1b$; $X_2=K_2(e-a)$; $Y_2=-K_2b$; $X_3=X_1+X_2$; $Y_3=Y_1+Y_2$

(5) During the synchronous parallel-network or parallel-off, namely when $I_a = I_b = I_c = 0$, performing the following calculations on the synchronous motor voltage signal and the system voltage signal

inputted to the computer:

(a) $\dot{U} = K_T(u_{AB} + u_{BC}\angle 120^0 + u_{CA}\angle 240^0) = U\angle\alpha$

(b) $\dot{U}_x = K_{XT}(u_{XAB} + u_{XBC}\angle 120^0 + u_{XCA}\angle 240^0) = U_x\angle\varepsilon$

(c) $\frac{\dot{U}}{\dot{U}_x} = \frac{U}{U_x}\angle\delta_x$

(d) $\overline{\delta}_x = \frac{\delta_1+\delta_2+\cdots\delta_n}{n}$ (wherein $\delta_1\delta_2\cdots\delta_n$ are the values of the first, the second ··· and the n^{th} δ_x measured within a certain time period; when a second measured value enters, the value of the first δ_1 is abandoned, and when the next measured value enters, the value of the second δ_2 is abandoned; analogically, the new measured values replace the old ones; and the time period and the value of n can be set.)

(e) $h = K_N U_{abj} * \cos\overline{\delta}_x$

(f) $i = K_N U_{abj} * \sin\overline{\delta}_x$

(g) $j = K_{XN} U_{xabj}$

(6) Comparing various electric parameters with respective given values, and alarming when the electric parameters are out of the prescribed ranges.

Compared with the single electric power angle vector graph depicted by the conventional power angle meter for measuring the operating state of the motor, the electric model graph, mechanical model graph and motor-end composite magnetic leakage graph depicted by the composite power angle meter of the present invention for measuring the operating state of the synchronous motor have the following advantages:

Comparisons are made in terms of the salient-pole synchronous motor and the non-salient-pole synchronous motor, respectively.

1. The comparison between the composite power angle meter of the salient-pole synchronous motor and the conventional power angle meter

a) The composite power angle meter of the salient-pole synchronous motor may display six graphs, and it displays not only the composite power angle of the salient-pole synchronous motor, but also the sub-figures of the composite power angle, with reference to Figure 5 to Figure 9; and it realizes the functions of image-alarming and sound-alarming. The PQ curve in the composite

power angle graph of Figure 5 defines the locus range of the vertex E_0 of the magnetic excitation lever, the composite magnetic leakage graph in Figure 20 defines the composite magnetic leakage range of the stator and rotor that the end heat-emitting of the synchronous motor permits, thus providing intuitional limit graph of the motor parameters for operators; however, the conventional power angle meter only displays the electric vector graph, as shown in Figure 6.

b) The composite power angle graph (Figure 5) displayed by the composite power angle meter of the salient-pole synchronous motor has double significations: in one aspect, it represents the electric power angle vector graph of the salient-pole synchronous motor, and in another aspect, it represents the mechanical power angle graph showed with the magnetic flux. The power angle represented by the composite power angle graph of the salient-pole motor has both electric and mechanical characteristics. However, the conventional power angle graph only shows electric vectors and only reflects the electric characteristics of the power angle.

c) The graphs displayed by the composite power angle meter further comprise the mechanical model graph of the synchronous motor, in addition to the electric vector graph. The stator and rotor levers in the mechanical model as shown in Figure 7 are the total composite magnetic flux $\Sigma\Sigma\Phi$ and magnetic excitation composite magnetic flux $\Sigma\Phi_0$ in the motor stator respectively, the elasticity coefficients of the quadrature-axis and direct-axis springs are $\frac{4mk^2w^2}{9l_q}$ and $\frac{4mk^2w^2}{9l_d}$ respectively (wherein m is the phase number of the motor stator, kw represents the effective turns of the stator coil, and l_q and l_d are the quadrature-axis and direct-axis synchronous inductance coefficients of the motor respectively), and the graph simulates the anticlockwise rotations of the motor stator and rotor. The mechanical models shown in Figure 5 and Figure 8 take the stator as a reference object, the stator lever and rotor lever are $\Sigma\Sigma\Phi$ and $\Sigma\Phi_0$ respectively, and the elasticity coefficients of the quadrature-axis and direct-axis springs are $\frac{2mk^2w^2}{9l_q}$ and $\frac{2mk^2w^2}{9l_d}$

respectively.

The mechanical power angle graph intuitionally reveals the mutual effective relationship between the motor stator and the motor rotor from mechanical aspect, and operators may refer to the mechanical model to understand the principle of the operating of the motor and adjust motor parameters precisely.

d) Compared with the electric vector graph, the composite power angle graph further includes assistant lines, as shown in Figure 5.

i.If the lengths of OE_0 and OU represent the magnetic excitation potential and the end voltage of the dynamotor respectively, UE_q and UE_d represent the quadrature-axis component and direct-axis component of the stator potential of the synchronous motor respectively, and E_qM and MU represent the active component and reactive component of the stator quadrature-axis potential of the synchronous motor, point M on segment OU or superposing point U respectively represent that the inductive reactive power done by the quadrature-axis potential is negative or zero, point E_q above, below or on the line OU respectively represent that the active power done by the quadrature-axis potential is positive, negative or zero; E_dN and NU represent the active component and reactive component done by the stator direct-axis potential of the synchronous motor respectively, point N on the segment OU, on the extension of the segment OU or superposing point U respectively represent that the inductive reactive power done by the direct-axis potential is negative, positive or zero, and point E_d above, below or on the line OU respectively represent that the active power done by direct-axis potential is positive, negative or zero.

ii.If the lengths of OE_0 and OU represent the magnetic excitation flux and the total composite magnetic flux in the stator coil of the dynamotor respectively, UE_q and UE_d respectively represent the quadrature-axis component and direct-axis component of the composite magnetic flux generated by the reaction of the stator armature of the synchronous motor.

iii.If the lengths of OE_0 and OU represent the rotor lever and stator lever of the synchronous motor respectively, UE_q and UE_d respectively represent the extended lengths of the springs by which

the rotor lever of the synchronous motor pulls the stator lever along directions of quadrature-axis and direct-axis, and segments E_qM and E_dN respectively represent the active length components generated by the extensions of the quadrature-axis spring and direct-axis spring, anticlockwise and clockwise pulls generate positive active power and negative active power respectively, segments MU and UN respectively represent the reactive components generated by the extensions of the quadrature-axis spring and direct-axis spring, the pull along the direction from point O to point U generates positive inductive reactive power, and the pull along the direction from point U to point O generates the negative inductive reactive power. Generally, the sum of $E_qM \pm E_dN$ may be regarded as the active power, and the sum of $MU \pm UN$ may be regarded as the reactive power, wherein '+' is adopted when forces generated by the springs orient the same direction, and '-' is adopted when forces generated by the springs orient opposite to each other.

e) Compared with electric vector graph (Figure 6), the composite power angle graph of the salient-pole synchronous motor (Figure 5) additionally includes the graph of the magnetic excitation adjustment signal.

By adding the magnetic excitation adjustment display, the operators are assisted to check the operating state of the automatic magnetic excitation adjuster intuitionally, judge the influence of the adjustment signal on the stable operation of the electric power system, and adjust the magnetic excitation accurately and duly in case of accident.

f) The newly added synchronous image (Figure 9) intuitionally shows the relative position of the rotor rigid body magnetic lever of the synchronous motor and the magnetic lever of the electric power system, which may assist the operators to adjust the rotation speed and end voltage of the motor accurately.

2. The comparison between the composite power angle meter of the non-salient-pole synchronous motor and the conventional power angle meter

a) The composite power angle meter of the non-salient-pole synchronous motor may display six graphs, and it displays not only the composite power angle of the non-salient-pole synchronous motor, but also the sub-figures of the composite power angle, with

reference to Figure 14 to Figure 18; and it realizes the functions of image-alarming and sound-alarming. The PQ curve in the composite power angle graph of Figure 14 defines the locus range of the vertex E_0 of the magnetic excitation lever, the composite magnetic leakage graph in Figure 22 defines the composite magnetic leakage range of the stator and rotor that the end heat-emitting of the synchronous motor permits, thus providing intuitional limit graph of the motor parameters for operators; however, the conventional power angle meter only displays the electric vector graph, as shown in Figure 15.

b) The composite power angle graph (Figure 14) displayed by the composite power angle meter of the non-salient-pole synchronous motor has double significations: in one aspect, it represents the electric power angle vector graph of the non-salient-pole synchronous motor, and in another aspect, it represents the mechanical power angle graph showed with the magnetic flux. The power angle of the synchronous motor represented by the composite power angle graph of the non-salient-pole motor has both electric and mechanical characteristics. However, the conventional power angle graph (Figure 15) only shows electric vectors and only reflects the electric characteristics of the power angle.

c) The graphs displayed by the composite power angle meter further comprise the mechanical model graph of the synchronous motor, in addition to the electric vector graph displayed by the conventional power angle meter. Thus, the mutual effective relationship between the motor stator and the motor rotor can be intuitionally revealed from mechanical aspect. The stator and rotor levers in the mechanical model as shown in Figure 16 are the total composite magnetic flux $\Sigma\Sigma\Phi$ and magnetic excitation composite magnetic flux $\Sigma\Phi_0$ in the motor stator respectively, the elasticity coefficient of the spring is $\frac{4mk^2w^2}{9l}$ (wherein m is the phase number of the motor stator, kw represents the effective turns of the stator coil, and l is the synchronous inductance coefficient of the motor), and the graph simulates the anticlockwise rotations of the motor stator and rotor. The mechanical models shown in Figure 14 and Figure 17 take the stator

as a reference object, the stator lever and rotor lever are $\Sigma\Sigma\Phi$ and $\Sigma\Phi_0$ respectively, and the elasticity coefficient of the spring is $\frac{2mk^2w^2}{9l}$.

The mechanical power angle graph intuitively reveals the mutual effective relationship between the motor stator and the motor rotor from mechanical aspect, and operators may refer to the mechanical model to understand the principle of the operating of the motor and adjust motor parameters precisely.

d) Compared with the electric vector graph, the composite power angle graph further includes assistant lines, as shown in Figure 14.

i. The lengths of OE_0 and OU represent the magnetic excitation potential and the end voltage of the motor respectively, and E_0U, E_0M and UM represent the stator potential of the motor, the active component and reactive component of the stator potential respectively; point M on the segment OU, on the extension of the segment OU or superposing point U represent that the motor generates capacitive reactive power, inductive reactive power or zero reactive power respectively. Point E_0 above, below or on line OU respectively represent that the motor is a dynamotor, is an electromotor, or has zero active power.

ii. The lengths of OE_0 and OU represent the magnetic excitation flux lever and the total magnetic flux lever in the stator coil of the motor respectively, and E_0U, E_0M and UM represent the extended length of the mechanical lever spring of the dynamotor, the active component and reactive component of the extended length of the spring respectively; point M on the segment OU, on the extension of the segment OU or superposing point U represent that the motor generates capacitive reactive power, inductive reactive power or zero reactive power respectively. Point E_0 above or below the lever OU or on the line OU respectively represent that the spring has an anticlockwise torsion, has a clockwise torsion or has no torsion with respect to the stator, and that the motor operates in manner of a dynamotor, an electromotor or zero active power.

iii. If the length of UE_0 represents the value of the apparent power W of the motor, the lengths of E_0M and UM represent the values of the active power and reactive power of the dynamotor

respectively.

iv. If the length of UE_0 represents the value of the stator current I of the motor, the lengths of E_0M and UM represent the values of the active component I_P and reactive component I_Q of the stator current of the motor respectively.

v. Compared with electric vector graph (Figure 15), the composite power angle graph of the non-salient-pole synchronous motor (Figure 14) additionally includes the graph of the magnetic excitation adjustment signal.

By adding the magnetic excitation adjustment display, the operators are assisted to check the operating state of the automatic magnetic excitation adjuster intuitionally, judge the influence of the adjustment signal on the stable operation of the electric power system, and adjust the magnetic excitation accurately and duly in case of accident.

vi. The newly added synchronous image (Figure 18) intuitionally shows the relative position of the rotor rigid body magnetic lever of the synchronous motor and the magnetic lever of the electric power system, which may assist the operators to adjust the rotation speed and end voltage of the motor accurately.

INDUSTRIAL APPLICABILITY

The present invention may intuitionally reflect the operating state of the synchronous motor from both electric and mechanical aspects, and may reveal the end composite magnetic leakage situation of the synchronous motor. Compared with the electric vector graph, the composite power angle graph of the motor depicted by the present invention further includes the mechanical model graph of the synchronous motor, which is helpful for operators of various specialties to dialectically analyze the operating state of the synchronous motor from both electric and mechanical aspects; the end composite magnetic leakage graph of the synchronous motor depicted by the present invention is helpful for operators to analyze and monitor the end heat-emitting situation of the synchronous motor. The method provided by the present invention may, in the electric power system industry, be an effective tool for users to apply in the analysis of the magnetic excitation characteristics, the magnetic excitation adjustment, the

synchronous parallel-network, the operation monitoring and controlling, and other tasks of the synchronous motor, so as to enable the synchronous motor to operate in an optimum state.